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Michigan Department of Transportation

Local Agency Program Highway Safety Improvement Program and High-Risk Rural Roads Safety Evaluation

FY2013

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Executive Summary

In 2017, more than 4,100 people were killed or seriously injured in traffic crashes occurring on Michigan's locally controlled roadways (1). Furthermore, locally controlled roadways represent nearly 92% of the total roadway miles in Michigan, while only supporting 47 percent of the annual vehicle miles traveled (VMT) (2). Because of the size and distribution of the local roadway network, strategically applying funding is critical in contributing to MDOT's Toward Zero Deaths (TZD) vision. Consistent with their data-driven approach towards safety, MDOT commissioned this study of the Highway Safety Improvement Program (HSIP), which incorporates both Safety Hazard Elimination (STH) and High-Risk Rural Road (HRRR) programs, for fiscal year 2013.

The primary objective of this assessment is to conduct a post-improvement evaluation study of the safety improvements implemented as a part of these programs, using both traditional and state-of-the-art Empirical Bayes (EB) methodology that is outlined in the American Association of State Highway Transportation Officials' (AASHTO) Highway Safety Manual (HSM) (3). The EB-method provides several analytical advantages over traditional approaches, including the consideration of changing traffic volumes, potential regression to the mean bias, as well as other unobserved factors which may impact the overall safety performance. **Table 1-1** summarizes the number of projects evaluated under each program, the total number of crashes occurring in the five years before and after installation, as well as overall program effectiveness as defined by traditional and EB-method techniques.

Table 1-1 - Summary of Post-Installation 2013 HSIP Programs

Program	Total Projects Evaluated	Pre-Installation Crashes	Post-Installation Crashes	Traditional Crash Reduction	EB-Method Safety Effectiveness
2013 STH	31	766	794	-3.7%	29.9%
2013 HRRR	8	122	73	40.2%	61.2%
Total	**39**	**888**	**867**	**2.4%**	**34.4%**

The highway locations included in the 2013 HSIP programs experienced a reduction of 21 crashes during the five-year analysis period. Additionally, 11 fatalities and 27 A-level injuries have been prevented by the FY2013 HSIP projects. While the results of the traditional post-installation evaluation suggest modest safety improvements, the results of the EB-method evaluation indicate greater improvements in safety performance as exhibited by the safety effectiveness in **Table 1-1**. Further consideration should be given to the project-level results to provide additional context as to the safety performance of each program (provided in the appendices).

In order to provide supplementary detail on the most cost-effective projects, an economic analysis was also conducted based on the results of the EB-method post-installation results and included an assessment of the benefit-cost ratio for each project and the overall programs. Additionally, an approximate time of return (TOR) based on the available data was also provided. **Table 1-2** summarizes the economic analysis.

Table 1-2 - Economic Analysis - Benefit-Cost Ratio and Time of Return

Program	Implementation Cost	Annual Cost	Annual Benefit	B/C	TOR
2013 STH	$5,851,427.56	$586,661.80	$2,226,244.98	3.79	2.62
2013 HRRR	$2,455,366.90	$209,219.25	$583,494.46	2.79	4.21
Total	**$8,306,794.46**	**$795,881.05**	**$2,809,739.45**	**3.53**	**2.95**

The economic results in **Table 1-2** indicate an overall positive benefit associated with these programs with 27 out of 39 projects realizing a benefit-cost ratio greater than 1.0. These findings were consistent with the safety results, where benefits were realized by both programs that also collectively experienced an overall reduction in crashes. Ultimately, the results of this study provide MDOT with more data-driven guidance as to the selection criteria for future HSIPs. Future work in this area should include additional post-installation evaluations of these programs as well as research to improve data-driven approaches to traffic safety.

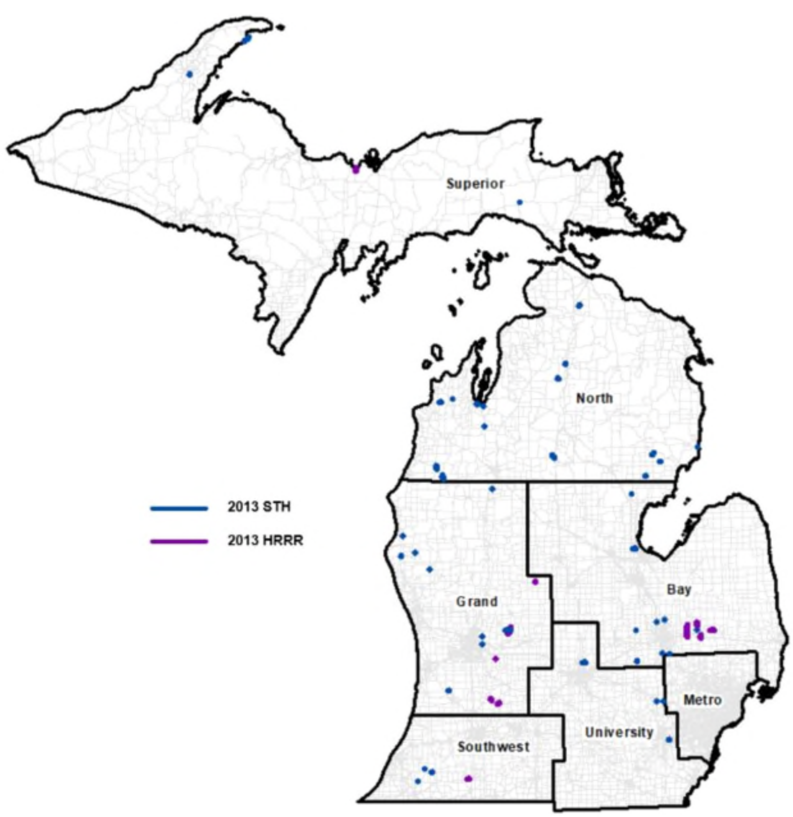
1. Introduction

Michigan's local highway network represents 47 percent of the vehicle miles travelled (VMT) on statewide roadways annually. Approximately 59 percent of statewide deaths or serious injuries result from traffic crashes on Michigan's locally controlled roadways. A reduction in serious injuries and fatalities on the local roadway system is a key component of the Michigan Department of Transportation's (MDOT) Toward Zero Death (TZD) vision. In order to address the critical safety issue, MDOT administers the Local Safety Program, which is responsible for distributing funding for highway safety improvements on the local roadway system as a part of the federal Highway Safety Improvement Program (HSIP). The HSIP is a core federal-aid program established by federal legislation in 2005 and continued under the Fixing America's Surface Transportation Act in 2015 (4). The goal of the HSIP is to achieve a significant reduction of traffic fatalities and serious injuries on all public roadways and is done so by utilizing a data-driven, strategic approach that focuses on performance (4).

In order to implement the aforementioned data-driven approach, MDOT commissioned this study of the HSIP for fiscal year (FY) 2013, which incorporates both Safety Hazard Elimination (STH) and High-Risk Rural Road (HRRR) programs. The primary objective of this assessment is to conduct a post-improvement evaluation study of the safety improvements that were implemented as a part of these programs, using both traditional and state-of-the-art Empirical Bayes (EB) methodology outlined in the American Association of Highway Transportation Officials (AASHTO) Highway Safety Manual (HSM) (3). The assessment included the evaluation of each completed project, along with additional analyses to determine which countermeasures were most effective through quantified results.

The 2013 local safety program included 39 distinct projects, with 31 receiving funding as a part of the STH program and eight projects funded through the HRRR program. It should be noted that each project may incorporate multiple intersections and highway segments along a single corridor. Additionally, projects often involved implementation of more than one safety treatment or countermeasure. Projects evaluated as a part of this study are shown in **Figure 1-1**.

Figure 1-1 - Map of 2013 HSIP Projects



In order to provide further detail on the most cost-effective projects, an economic analysis was also conducted based upon the results of the post-installation evaluation and included an assessment of the benefit-cost ratio for each project and overall programs as well as an approximate time of return (TOR) based upon the available data. The results of this study should assist MDOT in future safety planning efforts related to the local agency program.

2. Purpose

In order to assess the effectiveness of the FY 2013 local agency programs, along with the specific safety treatments and countermeasures implemented as a part of these programs, it was necessary to perform a comprehensive post-installation study. The study was completed by examining the pre-installation existing conditions at each project location, along with the specific details regarding the safety treatments and countermeasures implemented in association with the relevant historical traffic crash and volume data. The impacts of each project, program, and specific countermeasures were assessed using two main analytical techniques:

1. A **traditional evaluation**, which was performed by considering the before (pre-installation) and after (post-installation) crash totals. This process is similar to what MDOT uses for the Time of Return (TOR) form. For reference, the TOR form is included with potential project submissions in consideration for HSIP funding.

2. A **state-of-the-art evaluation using the Empirical-Bayes (EB) method**, which is outlined in the HSM. The main advantage of the EB-method is that unlike traditional safety evaluations, the EB-method considers changes in site conditions (such as traffic volumes) as well as potential regression-to-the-mean bias often present in such safety analyses (3).

In order to assess the effectiveness of specific safety treatments installed during the FY 2013 programs, projects were also grouped by the category of safety treatment installed, including:

- Access Management
- Centerline Rumble Strips
- Clear zone
- Flashing Yellow Arrow Signal
- Guardrail
- High-Friction Surface Treatment
- Horizontal Alignment
- Offset Left-Turn Lane
- Road Diet
- Roadway Paving
- Shoulder Paving
- Shoulder Widening
- Sight Distance Improvements
- Sign-Mounted Flashing Beacons
- Sign Upgrades
- Signal Modernizations
- Vertical Alignment

Based upon both the traditional and EB-methods, an economic analysis was also performed to provide MDOT with additional detail on the impact of the programs. This analysis included evaluation at both the project and program levels and was identified by two key metrics.

- **Benefit-Cost Ratio** – The road user benefit as defined by the reduction in traffic crashes determined by the EB-method analysis divided by the cost to implement the projects.
- **Time-of-Return (TOR)** – The number of years until the road user benefit (as defined by the reduction in traffic crashes determined by the EB-method analysis) outweighed the installation as well as operations and maintenance costs.

3. Methodology

In order to perform the comprehensive post-installation study, it was first necessary to identify the appropriate analytical methodology. This section describes the post-installation study methodology used to determine the safety benefits of the implemented projects in addition to the methodology used within the economic analysis. Additionally, details are provided related to the data collection and aggregation completed to achieve the study objectives.

3.1. Post-Installation Study Methodology

Initially, it was determined in consultation with MDOT that five years of pre-installation (before period) and post-installation (after period) data would be used in the evaluation. Using five years of data is consistent with the methodology recommended in the HSM, which specifies using three to five years of data in each period when performing an EB-based assessment (3). It should be noted that crashes that occurred the year of installation (2013) are not included in the analyses.

3.1.1. Traditional Before and After Analysis

Before applying the state-of-the-art EB-method, a comparison of the pre- and post-installation periods was performed using traditional analytical techniques. This involved calculating a percent reduction (or increase) in crashes after the implementation of safety treatments according the **Equation 1**. The traditional analysis was performed for each program, project and treatment group. Percent reductions are provided separately for fatal and injury crashes (or crashes resulting in a fatality or A-, B-, or C-level injury, referred to as FI) and property damage (PDO) crashes.

$$Percent\ Reduction\ (\%) = \left(\frac{Before\ Period\ Crash\ Total - After\ Period\ Crash\ Total}{Before\ Period\ Crash\ Total}\right) \qquad \text{(Equation 1)}$$

3.1.2. EB-Method Before and After Analysis

While the traditional before and after analysis provides an important context to the understanding of each project's overall impact, there are several limitations that reduce the usefulness of the results. Specifically, traffic volumes (along with other potentially unobserved factors) may change from pre- to post-installation periods, leading to a direct impact on the relative exposure effecting the likelihood for traffic crashes to occur. In addition, the predictive method outlined in the HSM provides several other notable advantages when compared to the traditional analysis methods, including:

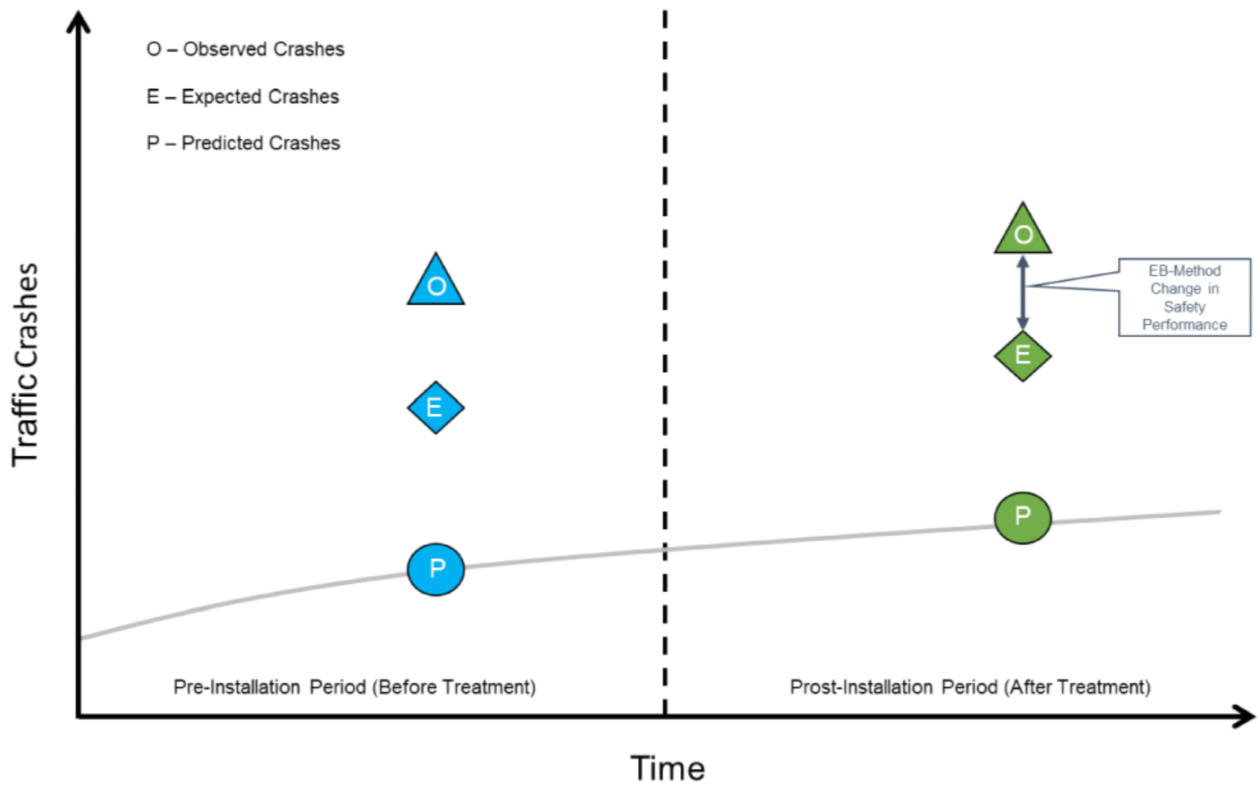
- Regression-to-the-mean bias is considered as a long-term expected average crash frequency and is utilized compared to short-term observed crash frequency;
- Reliance on the availability of limited crash data for one site is reduced as predicted relationships are incorporated based upon data from many similar sites;
- The method considers the fundamentally non-linear relationship between crash frequency and traffic volume; and
- The predictive models used are based upon a negative binomial distribution, which is better suited to address the variability of crash data than traditional modelling techniques (3).

The EB-method combines a site's observed crash frequency with a predicted crash frequency developed using a statistical model, referred to as a safety performance function (SPF) in order to estimate an expected average crash frequency (3). SPFs are regression equations developed to estimate a predicted average crash frequency for a specific site type based upon given conditions (3). More information related to the development and applications or SPFs can be found in the HSM (3). The HSM also describes the process for estimating locally derived SPFs which may better fit crash data within a specific jurisdiction (3). This is particularly relevant, as MDOT has recently funded research to estimate SPFs for urban and rural intersections and segments in Michigan (5, 6, 7). For the purposes of this evaluation, Atkins utilized these Michigan-specific SPFs in the EB-method for all projects.

Crash modification factors (CMF) were used to further tailor SPF equations to a specific roadway based on geometric and other defining characteristics. CMFs are available for both segments and intersections, and are generally categorized based on area type, crash type, and crash severity. For purposes of the analysis, CMFs from the HSM and CMFs provided by the Michigan Specific SPF research were considered. CMFs in the HSM were only utilized if a Michigan-specific CMF was not available in the SPF research for a certain factor.

In the context of an EB-method before and after evaluation study, the HSM recommends comparing a site's observed after treatment crash frequency with the expected crash frequency without treatment to determine the safety effectiveness of implemented treatments and countermeasures (3). **Figure 3-1** shows the before and after evaluation.

Figure 3-1 - Reduction in Crashes via EB-Method Before and After Evaluation (9)



The reduction in crashes due to the applied treatment can be represented as safety effectiveness or as a treatment crash modification factor, shown in Equations 2 and 3, respectively. Safety effectiveness was calculated for FI, PDO, and total crashes.

$$Safety\ Effectiveness\ (\%) = 100\% \times \left(1 - \frac{(Observed\ After\ Period\ Crashes)}{(Expected\ After\ Period\ Crashes\ without\ Treatment)}\right) \quad \text{(Equation 2)}$$

$$Treatment\ CMF = \left(\frac{Observed\ After\ Period\ Crashes}{Expected\ After\ Period\ Crashes\ without\ Treatment}\right) \quad \text{(Equation 3)}$$

A test for significance was conducted based upon the techniques outlined in Chapter 9 of the HSM (3) and included the calculation of variance with respect to each program, project, and treatment. The variance is combined with the safety effectiveness of each program, project, and treatment and is compared with a reference value in order to determine statistical significance. The variance also provides a means for calculating an unbiased safety effectiveness for each group. For the purposes of this evaluation, reference values were selected in order to test for significance at a 95 percent level of confidence.

3.2. Economic Analysis Methodology

In addition to the before and after evaluation, an economic analysis of each project and the overall program was performed which was completed by examining the results of the EB-method as described in Section 3.1.2. The equivalent uniform annual cost and equivalent uniform annual benefit were determined for each project and used to calculate a benefit-cost ratio (BCR) and TOR, as shown in equations 4 and 5:

$$BCR = \left(\frac{Annual\ Road\ User\ Benefit}{Annual\ Road\ User\ Cost}\right) \quad \text{(Equation 4)}$$

$$TOR = \left(\frac{Project\ Implementation\ Cost}{Annual\ Road\ User\ Benefit}\right) \quad \text{(Equation 5)}$$

3.2.1. Road User Benefits

Road user benefits were determined by considering the EB-method evaluation results. Given the reduction (or increase) in observed crash frequency compared to the expected crash frequency, a net benefit in dollars was assigned based upon the National Safety Council (NSC) document entitled Estimating the Costs of Unintentional Injuries, which is consistent with the crash costs that MDOT typically uses to calculate time of return (TOR) (10). The economic costs detailed by the NSC were used in conjunction with a query from MTCF during the study period (2008-2018) in order to determine costs for FI and PDO crashes separately. These data are summarized in **Table 3-1** and calculations for individual crash costs are shown in **Equations 6 and 7**.

Table 3-1 - Summary of FI and PDO Crashes

Severity Level	NSC Crash Cost (2017)	Frequency	Distribution of All Severity Levels	Distribution of FI Crashes Only
Fatal	$1,615,000	9,695	0.30%	1.61%
A-Injury	$93,800	51,142	1.56%	8.49%
B-Injury	$27,100	153,301	4.69%	25.45%
C-Injury	$22,300	388,299	11.87%	64.45%
PDO	$11,900	2,669,287	81.59%	--
Total	--	3,271,724	100%	100%

$$FI\ Crash\ Cost = (0.0161 \times \$1{,}615{,}000) + (0.0849 \times \$93{,}800) + (0.2545 \times \$27{,}100) + (0.6445 \times \$11{,}300) = \$\mathbf{55,222.49} \quad \text{(Equation 6)}$$

$$PDO\ Crash\ Cost = \$11{,}900 \quad \text{(Equation 7)}$$

An annual road user benefit for each site was calculated based upon the reduction in annual FI crashes and PDO crashes after treatments had been implemented based upon the results of the EB-method analysis. This is shown in **Equations 8** through **10**.

$$EUAB_{FI} = Annual\ Average\ Reduction\ in\ FI\ Crashes\ at\ Site \times \$55{,}222.49 \quad \text{(Equation 8)}$$

$$EUAB_{PDO} = Annual\ Average\ Reduction\ in\ PDO\ Crashes\ at\ Site\ \times \$11{,}900.00 \quad \text{(Equation 9)}$$

$$EUAB_{Total} = EUAB_{FI} + EUAB_{PDO} \quad \text{(Equation 10)}$$

3.2.2. Road User Costs

Road user costs were determined by the summation of initial implementation costs provided by MDOT for each project. Annual operation and maintenance costs are included in this analysis; however, it should be noted that these are the responsibility of the Local Agency. Additionally, a typical life cycle of each treatment was also estimated in coordination with MDOT based upon recent experience with such treatments. Using the life cycle information, an equivalent uniform annual cost was estimated for each project.

3.3. Data Collection

In order to perform the post-installation evaluation, it was necessary to collect and aggregate data from several sources towards developing a comprehensive database for analysis. Data collection included aggregating data related to each implemented project, existing conditions at the project locations, as well as historical traffic crash and volume data associated with each project location.

3.3.1. Fiscal Year 2013 Project Information

Details of the completed projects were provided by MDOT to Atkins, including the following key information related to the project:

- Funding source (STH or HRRR)
- Location and extents of the project; and
- Safety treatments and/or countermeasures implemented.

Atkins began investigating the details of each project. Each project was disaggregated into the homogenous highway segments and intersections that were incorporated within the boundaries of the project. While some projects were specific to a single intersection or highway segment, some projects incorporated locally controlled highway corridors that were made up of several intersections and/or highway segments. In order to appropriately analyze the safety impacts of the treatments installed, it was necessary to identify the single homogenous highway elements (intersections or segments) that make up a single project. **Figure 3-2** provides an example of a complex project completed in the Grand Region that included safety upgrades to a 0.6-mile corridor and three intersections.

Figure 3-2 - Example of a Single Complex HSIP Project Incorporating Multiple Intersections and Segments

Several additional elements related to each unique highway element were also collected via historical satellite and street view imagery for the purposes of estimating CMFs, including:

- Geometric site conditions (lane width, intersection skew, etc.)
- Presence of street lighting
- Access point density (driveways per mile)
- Presence of centerline or shoulder rumble strips;
- Passing lanes, parking lanes or exclusive turn lanes
- Roadside conditions (presence of fixed objects, roadside hazard rating, or shoulder characteristics); and
- Traffic signal phasing and turning movement prohibitions (right-turn-on-red prohibitions)

3.3.2. Historical Traffic Crash and Volume Data

Once the existing condition data was collected for each unique highway segment and intersection, Atkins merged historical traffic crash and volume data related to each element. Historical traffic crash data was collected for each segment and intersection from the annual traffic crash database maintained by MDOT (Roadsoft). Each crash occurring from 2008 to 2018 was mapped in ArcGIS according to the X and Y coordinates associated with the crash ID number. Crashes were then identified as cocurring in the pre- or post-installation period by year and joined spatially with with project segments and intersections based upon the following criteria:

- Segments – Crashes were joined spatially with a deviation tolerance of 10 feet (used for coordinates that were not directly places on roadway centerlines). Only mid-block crashes were applied to segments per HSM methodology. Intersections were identified along each corridor using the Michigan Geographic Framework, and crashes occurring within 300 feet of each intersection were exlcuded from the segment query.
- Intersections – Crashses were joined spatially using a 300 feet radius around the center point of each project intersection.

Historical traffic volume data were collected from the annual Highway Performance Monitoring System (HPMS) shapefiles provided by the Federal Highway Administration (FHWA). The shapefiles were joined to project segments and were used to estimate pre- and post-installation traffic volumes. Additionally, the HPMS shapefiles were also spatially associated with each project intersection, facilitating the developmnent of entering volumes for each approach. An algorithm was developed to determine major and minor enteirng volumes for each intersection.

4. Post-Installation Safety Evaluation

Following data collection, Atkins performed both traditional and EB-method post-installation safety evaluations. Each treated highway segment and intersection were analyzed separately and aggregated by project. Separate evaluations were completed for each program, project, and implemented treatment. For example, Project number STH-22 consisted of guardrail upgrades at 8 locations in Iosco County. Each of those locations had a separate segment represented in the geodatabase. For analysis purposes, those segments are initially analyzed independently then summed together to provide a project level output. A summary of the individual segments and intersections, as well as pre-installation and post-installation crash details are provided in **Table 4-1**.

Table 4-1 - Summary of HSIP Treated Highway Segments and Intersections Evaluated

Program	Total Projects Evaluated	Analyzed Segments	Analyzed Intersections	Pre-Installation Crashes	Post-Installation Crashes
2013 STH	31	40	16	766	794
2013 HRRR	8	10	1	122	73
Total	**39**	**50**	**17**	**888**	**867**

In total there were 39 projects evaluated in the post-installation study for FY 2013 programs and were comprised of 67 unique highway elements (50 segments and 17 intersections). There was a reduction in total observed traffic crashes during the study period, from 888 total crashes over the five-year pre-installation period to 867 total crashes during the five-year post-installation period, representing a 2.4 percent reduction. **Table 4-2** documents the amount of fatalities in addition to A-, B-, and C-level injuries that were experienced during each study period for each program. Note that a single crash may have multiple injuries.

Table 4-2 - Summary of Person-Level Pre-Installation and Post-Installation Fatalities and Injuries

Program	Pre-Installation Period				Post-Installation Period			
	Fatalities	A-Inj.	B-Inj.	C-Inj.	Fatalities	A-Inj.	B-Inj.	C-Inj.
2013 STH	6	34	56	204	1	8	51	167
2013 HRRR	7	4	11	22	1	3	11	20
Total	**13**	**38**	**67**	**226**	**2**	**11**	**62**	**187**

Table 4-2 demonstrates that the number of fatalities decreased from 13 to 2 (or 84.6 percent) following project implementation. Similar trends were observed for A-, B- and C-injuries, where they collectively decreased from 331 to 260 (or by 21.5 percent). Specifically, the amount of A-level injuries was reduced by 71 percent from pre-installation to post-installation. While these reductions in crash frequency are promising they do not account for the changes in volume, site characteristics, or other unobserved factors that may impact the frequency of traffic crashes between each period. For example, a decrease in volume between the two periods would generally lead to a decrease in exposure and generally result in less crashes. Conversely, if there was an increase in volume between the two periods, the amount of exposure would increase and generally lead to more crashes. The relationship between volume and crash expectancy is non-linear and tends to regress to the mean over time. Therefore, the EB-method is used to provide a more accurate picture of crash performance and account for unobserved factors related to the safety performance of roadways and intersections.

Table 4-3 provides a summary of the average volumes observed during each analysis period for segments (provided in vehicle-miles-traveled (VMT)) and intersections (provided in daily entering vehicles at each intersection).

Table 4-3 - Summary of Project Segment and Intersection Traffic Volumes

Program	Segments			Intersections		
	Pre-Installation VMT	Post-Installation VMT	Percent Change	Pre-Installation Total Entering Vehicles	Post-Installation Total Entering Vehicles	Percent Change
2013 STH	120,101,641	98,111,223	-18.3%	450,264,000	485,433,847	7.8%
2013 HRRR	112,937,911	137,055,547	21.4%	2,941,900	2,367,481	-19.5%
Overall	**233,039,553**	**235,166,770**	**0.91%**	**453,205,900**	**487,801,329**	**7.6%**

Overall, segment volumes remained relatively consistent between the pre- and post-implementation periods. Segment volumes were found to decrease for the 2013 STH program approximately by 18.3 percent and increase for the 2013 HRRR program by 21.4 percent. Conversely, the 2013 STH intersections experienced a 7.8 percent increase in total entering vehicles, while the 2013 HRRR intersection had a decline in volume of 19.5 percent. For additional context, volumes were combined with crash frequencies to develop crash rates for each project studied. **Tables 4-4** and **4-5** provide volume, crash frequency and crash rate information for segments and intersections, respectively.

Table 4-4 - Summary of Pre- and Post-Installation HSIP Segment Crash Rates

Program	Analyzed Segments	Vehicle Miles of Travel		Total Segment Crashes		Segment Crash Rate*	
		Before	After	Before	After	Before	After
2013 STH	40	120,101,641	98,111,223	84	75	69.94	76.44
2013 HRRR	10	112,937,911	137,055,547	121	71	107.14	51.80
Total	**50**	**233,039,553**	**235,166,770**	**205**	**146**	**87.97**	**62.08**

*Crash rate shown in segment crashes per 100,000,000 vehicle miles travelled

Table 4-5 - Summary of Pre- and Post-Installation HSIP Intersection Crash Rates

Program	Analyzed Intersections	Total Entering Vehicles		Total Intersection Crashes		Intersection Crash Rate*	
		Before	After	Before	After	Before	After
2013 STH	16	450,264,000	485,433,847	682	719	1.51	1.48
2013 HRRR	1	2,941,900	2,367,481	1	2	0.34	0.84
Total	**17**	**453,205,900**	**487,801,329**	**683**	**721**	**1.51**	**1.48**

*Crash rate shown in intersection crashes per 1,000,000 entering vehicles

Similar to overall program trends observed in **Table 4-1**, the total crash rate was found to decrease for segments by 25.89 crashes per 100 million vehicle-miles (MVM) or 29.4 percent and appears to correlate with the reduction in crash frequency since volume is largely consistent between the pre- and post-installation periods. At the program level, the 2013 HRRR segments demonstrate a substantial reduction in crash rate from 107.14 to 51.80 crashes per

100 MVM or 51.7 percent. However, for the 2013 STH program, the crash rate for segments was found to increase from 69.97 to 76.44 crashes per 100 MVM or 9.2 percent. The segment findings in **Table 4-4** indicate the importance of accounting for volume when evaluating crash numbers since the observed crash frequency reduced by 10.7 percent while the volume increased by 19 percent.

In **Table 4-5,** the overall crash rate of project intersections was found to decrease from 1.51 to 1.48 crashes per million entering-vehicles (MEV) or 2 percent and was largely attributed to the 2013 STH funded projects. More importantly, the reduction in crash rate was realized despite an increase of total observed crashes from 683 to 721 or 5.6 percent. The increase in volume of 7.6 percent from pre- to post-installation offset the increase in frequency of observed crashes. While these aggregate results provide insight to the impact of the 2013 safety programs, the results of the EB-method before and after analysis are necessary given that there are still several limitations related to the use of traditional crash rates alone (3).

4.1. Traditional Post-Installation Evaluation

The traditional post-installation evaluation results represent a comparison of the pre- and post- installation observed crash counts according to the methodology outlined in Section 3.1.1. This section details the results of the program and treatment evaluations, while an evaluation of each project can be referenced in **Appendix A**.

4.1.1. Traditional Program Evaluation

Table 4-6 provides a summary of FI and PDO crash frequencies for each funding program.

Table 4-6 - FI and PDO Crash Frequency's by Program

Program	Pre-Installation Annual Average Crashes			Post-Installation Annual Average Crashes			Crash Reduction		
	FI	PDO	TOT	FI	PDO	TOT	FI	PDO	TOT
2013 STH	40.2	113	153.2	32.2	126.6	158.8	19.9%	-12.0%	-3.7%
2013 HRRR	7	17.4	24.4	5	9.6	14.6	28.6%	44.8%	40.2%
Total	**47.2**	**130.4**	**177.6**	**37.2**	**136.2**	**173.4**	**21.2%**	**-4.4%**	**2.4%**

A 21.2 percent reduction in fatal and injury crashes was found when considering both funding sources. This finding is consistent with the person level summary provided in **Table 4-2**. In contrast, property damage only crashes were found to increase by 4.4 percent between the pre- and post- installation periods which may be attributed to the increase in overall volume of 5.3 percent when considering both segments and intersections. Finally, when combining both severity levels, total crashes were found to decrease by 2.4 percent.

4.1.2. Traditional Treatment Evaluation

An assessment of each implemented treatment was conducted separately for intersections and segments to determine the effectiveness of treatments implemented as part of both programs. For reference, projects with multiple treatments were excluded from this analysis to more accurately quantify the safety performance of each individual treatment. As such, the sample size for some treatments are low and does not allow for any meaningful conclusions. **Tables 4-7** provides a summary of pre- and post-installation crashes for each treatment implemented for intersections and segments, respectively.

Table 4-7 - Traditional Post-Installation Evaluation of Intersection and Segment Treatments

Grouping	Treatment Type	Sites	Observed Crashes - Before			Observed Crashes - After			Percent Reduction		
			FI	PDO	TOT	FI	PDO	TOT	FI	PDO	TOT
Lane Departure	Guardrail	22	12	25	37	10	21	31	16.7%	16.0%	16.2%
	Roadway Paving	1	3	2	5	2	0	2	33.3%	100%	60.0%
	Shoulder Widening	5	2	3	5	3	4	7	-50.0%	-33.3%	-40.0%
	High Friction Surface Treatment	2	7	24	31	1	16	17	85.7%	33.3%	45.2%
	Shoulder Paving	2	9	13	22	3	10	13	66.7%	23.1%	40.9%
	Clearzone	3	3	1	4	3	0	3	0.0%	100%	25.0%
	Horizontal Alignment	6	4	2	6	2	3	5	50.0%	-50.0%	16.7%
	Centerline Rumble Strips	4	19	61	80	15	28	43	21.1%	54.1%	46.3%
Segment	Vertical Alignment	2	1	3	4	2	4	6	-100%	-33.3%	-50.0%
	Sign Upgrades	1	1	1	2	3	1	4	-200.0%	0.0%	-100%
	Access Management	1	0	0	0	0	0	0	N/A	N/A	N/A
	Road Diet	1	4	5	9	5	10	15	-25.0%	-100%	-66.7%
Intersection	Flashing Beacon Install (Warning Sign)	2	9	16	25	6	10	16	33.3%	37.5%	36.0%
	Traffic Signal Upgrade	8	143	462	605	121	535	656	15.4%	-15.8%	-8.4%
	Sight Distance Improvements	1	3	4	7	3	0	3	0.0%	100%	57.1%
	Offset Left Turn Lane	1	8	23	31	4	27	31	50.0%	-17.4%	0.0%
	Sign Upgrades	3	7	4	11	0	2	2	100%	50.0%	81.8%
	Vertical Alignment	2	1	3	4	3	10	13	-200.0%	-233.3%	-225.0%

For intersections, traffic signal upgrades (signal modernization, flashing yellow arrow, etc.) had the largest sample size (n=8) and provided a 15.4 percent reduction of FI crashes. Sign upgrades provided the greatest overall reduction in crashes, where both FI and PDO crashes were reduced by 100 and 50 percent, respectively. Guardrail provided the largest sample size (n=22) among segment treatments and realized a 16.2 percent reduction in total crashes, with a 16.7 percent reduction in FI crashes. Although sample size and total crash frequencies are minimal for other treatments studied, the results for the high friction surface treatment are encouraging, where an 85.7 percent reduction in FI crashes was experienced. Each of these treatments is representative of a relatively small sample size and should not be used for development of Crash Modification Factors (CMF).

4.2. EB-Method Post-Installation Evaluation

The EB-Method, as stated in Section 3.1.2, uses a state-of-the-art statistical approach to account for changes in traffic volume, site characteristics, and other unobserved factors when assessing safety effectiveness. Similar to the traditional approach, Atkins has evaluated the 2013 HSIPs at a project, program, and treatment level. The following text details the results of the EB-method evaluation for the programs and treatments considered in this study, while the details on the EB-method results by project can be referenced in **Appendix A**.

4.2.1. EB-Method Program Evaluation

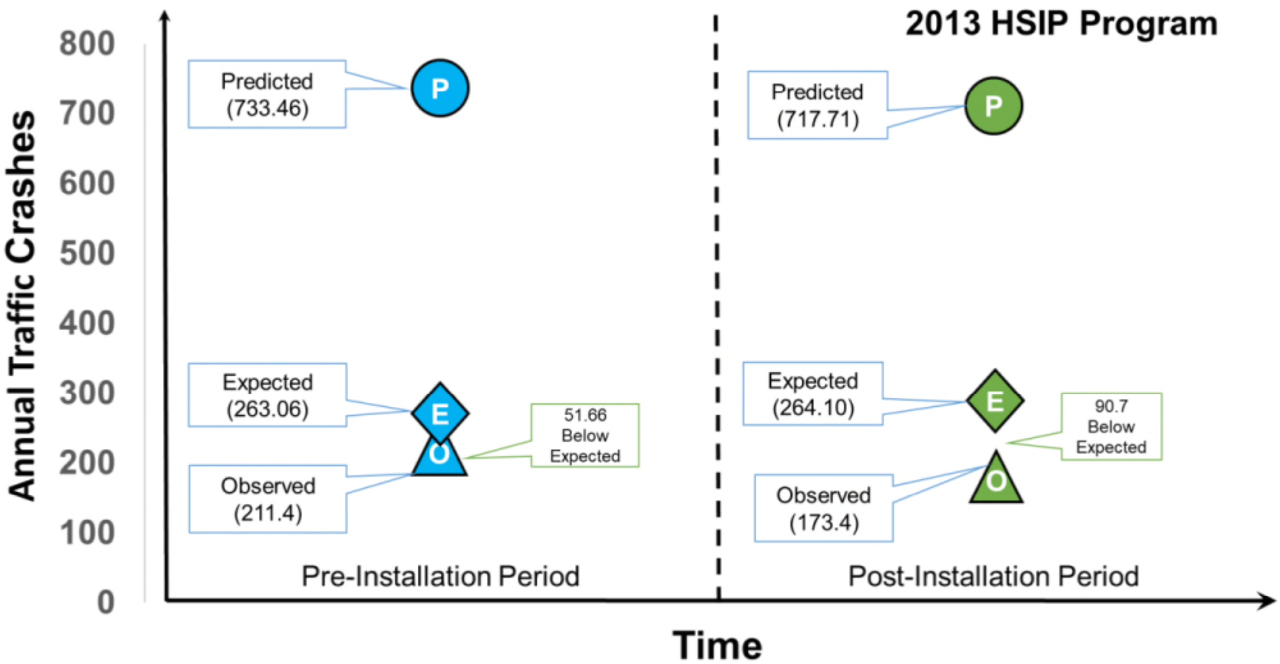
Table 4-8 displays the expected annual average crashes that would be expected without any treatment (based upon statistical techniques outlined in Section 3.1.2) and the observed annual average crashes in the post-installation period for each program. Additionally, **Table 4-8** also shows the unbiased safety effectiveness based on these results, as specified by Chapter 9 of the HSM (3).

Table 4-8 - EB-Method Post-Installation Evaluation Results

Program	Expected Annual Average Crashes Post-Installation without Treatment			Observed Annual Average Crashes Post-Installation with Treatment			Safety Effectiveness		
	FI	PDO	TOT	FI	PDO	TOT	FI	PDO	TOT
2013 STH	65.01	161.43	226.48	32.2	126.6	158.8	50.5%	21.6%	29.9%
2013 HRRR	12.10	25.68	37.62	5	9.6	14.6	58.7%	62.6%	61.2%
Total	77.11	187.11	264.10	37.2	136.2	173.4	51.8%	27.2%	34.3%

The results of the EB-method evaluation suggest an even greater improvement of safety performance due to the implementation of the STH and HRRR projects. **Figure 4-1** provides a visual representation of the program-level HSIP results. **Appendix C** also provides visual representations of the EB-method results for the 2013 STH and 2013 HRRR programs. In addition to each program indicating an overall positive safety performance, 33 out of 39 projects also demonstrated notable safety benefits in terms of safety effectiveness.

Figure 4-1 - 2013 HSIP Program EB-Method Results



Additionally, it is critical to assess the statistical significance of each program, which is shown in **Table 4-9**. Using methodology from the HSM, groups with a calculated test statistic greater than 2.0 are considered statistically significant at a 95 percent level of confidence.

Table 4-9 - EB-Method Post-Installation Evaluation Results - Test for Significance

Program	Safety Effectiveness			Test for Significance*			Significant at 95%		
	FI	PDO	TOT	FI	PDO	TOT	FI	PDO	TOT
2013 STH	0.50	0.22	0.30	5.43	2.70	4.80	Yes	Yes	Yes
2013 HRRR	0.59	0.63	0.61	2.95	4.65	5.33	Yes	Yes	Yes

*Greater than 2.0 indicates statistically significant result at a 95% level of confidence

In addition to the collective increase in unbiased safety performance, the results are also statistically significant at a 95% level of confidence for each program and crash severity level.

4.2.2. EB-Method Treatment Evaluation

A similar EB-method post-installation evaluation was conducted on the same 13 treatments that were identified in Section 4.1.2; which includes the evaluation of five intersection-related treatments and eight segment-related treatments.

4.2.2.1. EB-Method Segment Treatment Evaluation

Table 4-10 shows each segment-related treatment along with the number of sites, the expected number of crashes without treatment, the observed number of crashes with treatment, as well as the unbiased safety performance.

Table 4-10 - EB-Method Post-Installation Evaluation Segment Treatment Results

Treatment	Sites	Expected Annual Average Crashes Post-Installation without Treatment			Observed Annual Average Crashes Post-Installation			Safety Effectiveness		
		FI	PDO	TOT	FI	PDO	TOT	FI	PDO	TOT
Guardrail	22	4.36	14.31	18.6	2	4.2	6.2	54.1%	70.7%	66.7%
Roadway Paving	1	0.73	0.64	1.39	0.4	0	0.4	44.9%	100%	71.2%
Shoulder Widening	5	1.21	2.63	3.87	0.6	0.8	1.4	50.5%	69.6%	63.8%
High Friction Surface Treatment	2	1.17	3.98	5.20	0.2	3.2	3.4	82.8%	19.6%	34.6%
Shoulder Paving	2	2.37	3.19	5.56	0.6	2	2.6	74.7%	37.3%	53.3%
Clearzone	3	0.81	0.57	1.38	0.6	0	0.6	25.7%	100%	56.4%
Horizontal Alignment	6	1.23	3.08	4.30	0.4	0.6	1	67.5%	80.5%	76.7%
Centerline Rumble Strips	4	5.32	14.6	19.7	3	5.6	8.6	43.6%	61.5%	56.4%
Vertical Alignment	2	0.40	1.51	1.91	0.4	0.8	1.2	-0.05%	47.0%	37.1%
Sign Upgrades	1	0.51	0.85	1.34	0.6	0.2	0.8	-17.3%	76.6%	40.5%
Access Management	1	0.39	1.35	1.73	0	0	0	100%	100%	100%
Road Diet	1	2.03	3.13	5.24	1	2	3	50.7%	36.1%	42.7%

Although a few of the treatments indicated a negative safety performance in the traditional analysis, each treatment indicated a positive overall safety performance in terms of safety effectiveness. However, Sign upgrade and vertical alignment adjustments each indicates negative safety performance for FI crashes for both the traditional analysis and EB-method. Although shoulder widening and road diets experienced a decrease in safety performance in the traditional analysis, the EB-method indicated a positive safety performance from these treatments. **Table 4-11** shows the significance testing results for each segment treatment.

Table 4-11 - EB-Method Post-Installation Evaluation Segment Treatment Results - Test for Significance

Treatment	Sites	Safety Effectiveness			Test for Significance			Significant at 95%		
		FI	PDO	TOT	FI	PDO	TOT	FI	PDO	TOT
Guardrail	22	54.1%	70.6%	66.7%	2.92	8.99	8.89	Yes	Yes	Yes
Roadway Paving	1	44.9%	100%	71.2%	1.53	N/A	3.43	No	N/A	Yes
Shoulder Widening	5	50.5%	69.6%	63.8%	1.79	4.03	3.92	No	Yes	Yes
High Friction Surface Treatment	2	82.8%	19.6%	34.6%	5.21	0.88	1.54	Yes	No	No
Shoulder Paving	2	74.7%	37.3%	53.3%	4.47	1.49	2.78	Yes	No	Yes
Clearzone	3	25.7%	100%	56.4%	1.02	N/A	2.18	No	N/A	Yes
Horizontal Alignment	6	67.5%	80.5%	76.7%	2.94	6.61	6.57	Yes	Yes	Yes
Centerline Rumble Strips	4	43.6%	61.5%	56.4%	1.97	5.20	4.93	No	Yes	Yes
Vertical Alignment	2	0.0%	47.0%	37.1%	0.36	1.72	1.38	No	No	No
Sign Upgrades	1	-17.3%	76.6%	40.4%	0.39	3.70	1.42	No	Yes	No
Access Management	1	100%	100%	100%	N/A	N/A	N/A	N/A	N/A	N/A
Road Diet	1	50.7%	36.1%	42.7%	1.99	1.42	1.89	No	No	No

Each treatment indicated a statistically significant increase in overall safety performance except for high friction surface treatments, sign upgrades, access management, and road diets. In general, the results provide an additional tool for MDOT to evaluate the impact of the specific treatments implemented as a part of these programs; however, a much larger and diverse sample size of data would be required to draw further conclusions. It is recommended that the agency continue to rely on the CMFs published in the HSM or CMF Clearinghouse (3, 8).

4.2.2.2. EB-Method Intersection Treatment Evaluation

Table 4-12 displays each intersection-related treatment along with the number of sites, the expected number of crashes without treatment, the observed number of crashes with treatment, as well as the unbiased safety performance.

Table 4-12 - EB-Method Post-Installation Evaluation Intersection Treatment Results

Treatment	Sites	Expected Annual Average Crashes Post-Installation without Treatment			Observed Annual Average Crashes Post-Installation			Safety Effectiveness		
		FI	PDO	TOT	FI	PDO	TOT	FI	PDO	TOT
Flashing Beacon Install	2	1.37	3.11	4.48	1.2	2	3.2	12.6%	35.7%	28.6%
Traffic Signal Upgrade	8	38.7	104.1	142.8	24.2	107	131.2	37.5%	-2.80%	8.13%
Sight Distance Improvements	1	2.60	4.75	7.33	0.6	0	0.6	77.0%	100%	91.8%
Offset Left Turn Lane	1	2.66	6.69	9.36	0.8	5.4	6.2	70.0%	19.3%	33.7%
Sign Upgrades	3	7.63	10.4	17.9	0	0.4	0.4	100%	96.2%	97.8%
Vertical Alignment	2	4.79	8.82	13.6	0.6	2.0	2.6	87.5%	77.3%	80.9%

Each intersection improvement indicated evidence of safety improvement. Unlike the traditional results, the vertical alignment treatment on approach to an intersection showed evidence of increased safety performance. Overall, in comparison to the traditional analysis, the EB-method also indicates improved safety performance; however, it also indicates a much greater safety performance than the traditional analysis. **Table 4-13** shows the statistical significance of each intersection treatment.

Table 4-13 - EB-Method Post-Installation Evaluation Intersection Treatment Results - Test for Significance

Treatment	Sites	Safety Effectiveness			Test for Significance*			Significant at 95%		
		FI	PDO	TOT	FI	PDO	TOT	FI	PDO	TOT
Flashing Beacon Install	2	12.6%	35.7%	28.6%	0.50	1.50	1.35	No	No	No
Traffic Signal Upgrade	8	37.5%	-2.80%	8.13%	4.98	0.29	1.43	Yes	No	No
Sight Distance Improvements	1	77.0%	100%	91.8%	5.54	N/A	19.0	Yes	N/A	Yes
Offset Left Turn Lane	1	70.0%	19.3%	33.7%	4.30	0.98	2.13	Yes	No	Yes
Sign Upgrades	3	100%	96.2%	97.8%	N/A	34.9	61.7	N/A	Yes	Yes
Vertical Alignment	2	87.5%	77.3%	80.9%	11.3	9.12	13.1	Yes	Yes	Yes

*Greater than 2.0 indicates statistically significant result at 95% level of confidence

Table 4-13 indicates that the overall increase in safety performance related to the sight distance improvements, offset left-turn lanes, sign upgrades, and vertical alignment was statistically significant. However, the safety increase performance implied for the flashing beacon installations and the traffic signal upgrades was not shown to be statistically significant, except for the reduction in FI crashes due to traffic signal upgrades. Consideration of the project-level results may provide further detail related to the impacts of these treatments. Overall the intersection treatments and segment treatments were shown to be effective in increasing safety performance.

5. Economic Analysis

In order to quantify the economic benefit to road users derived via the 2013 HSIP program, further analysis was conducted based up on the results of both the EB and traditional methods. The following sections detail the results of the economic analysis at the program level using the BCR and TOR metrics identified in Section 3.2 using the EB-method. Additionally, best-performing projects are identified based upon BCR for each program. Details of the economic analysis at the project-level, including BCR and TOR results can be found in **Appendix B**.

5.1. Economic Analysis of 2013 HSIP

Table 5-1 shows the annual average reductions in FI and PDO crashes associated with each program from the results of the EB-method analysis as well as an estimated annual benefit for road users based upon the FI ($55,222.49) and PDO ($11,900) crash costs. **Table 5-2** shows the total implementation and annual costs associated with each program, along with their relative benefit, BCR and TOR.

Table 5-1 - Economic Analysis - Annual Road User Benefit

Program	Annual Average Reduction			Road User Benefits		
	FI	PDO	TOTAL	FI Crash Cost	PDO Crash Cost	Annual Benefit
2013 STH	32.8	34.83	67.68	$55,222.49	$11,900	$2,226,244.98
2013 HRRR	7.1	16.1	23.0	$55,222.49	$11,900	$583,494.46

Table 5-2 - Economic Analysis - Benefit-Cost Ratio and Time of Return (TOR)

Program	Implementation Cost	Annual Cost	Annual Benefit	B/C	TOR
2013 STH	$5,851,427.56	$586,661.80	$5,448,003.43	9.29	1.07
2013 HRRR	$2,455,366.90	$209,219.25	$1,242,406.23	5.94	1.98

Consistent with the safety analysis results, benefits have been realized through both the 2013 STH and 2013 HRRR programs which both experienced a reduction in FI, PDO, and total crashes. It is important to consider the results of specific projects within each program when considering these results (**Appendix B**).

5.2. Best-Performing Projects

The preceding program-level results capture both high- and low-performing projects on an aggregate basis. Further review of the project-level results provides example of high-performing projects that are a result of appropriate safety planning and can provide guidance into improving further selection criteria. It is worth nothing that in addition to the program-level economic analysis results, 27 projects out of 39 demonstrated BCRs of greater than 1.0, providing examples of successful safety projects conducted as a part of these programs. **Table 5-2** shows the top ten performing projects overall for all programs ranked by BCR.

Table 5-3 - Top Ten Overall Projects by BCR

Rank	Program	Lead Agency	Project Location	Work Performed	Implementation Cost	Annual Benefit	BCR	TOR
1	2013 STH	Oceana County Road Commission	72nd Ave from North of Woodrow Rd to Shelby Rd; York Rd & Warren Rd; 192nd Ave & Wilke Rd; Oceana Drive & Monroe Rd	Sign Upgrades	$15,450.98	$560,970.30	222.0	0.03
2	2013 STH	Livingston County Road Commission	Grand River Avenue at Old US 23 in Brighton Township; Grand River Avenue at Kensington Road in Brighton and Green Oak Townships	Traffic Signal Upgrade	$155,133.91	$489,546.31	193.7	0.32
3	2013 STH	Grand Traverse County Road Commission	Sparling Road at Summit City Road in Paradise Township	Sight Distance Improvements; Sign Upgrades	$13,000.00	$167,205.34	148.1	0.08
4	2013 STH	Kent County Road Commission	Spaulding Avenue at Ada Drive in Ada Township	Traffic Signal Upgrade	$84,776.82	$199,232.46	20.00	0.43
5	2013 HRRR	Barry County Road Commission	Orchard Road-between Pleasant Lake Road and Kingsbury Road in Barry Township; Norris Road-between Hayward Road and Guernsey Road. in Orangeville Township	Shoulder Widening; Clear zone; Horizontal Alignment; Guardrail	$160,131.75	$91,082.18	9.37	1.76
6	2013 HRRR	St. Joseph County Road Commission	Broadway Road between Krull Road and Ferguson Road in Fabius Township	Guardrail	$25,078.60	$13,458.71	8.84	1.86
7	2013 STH	Keweenaw County Road Commission	Gay-Lac La Belle Road from Gay to Lac La Belle Road in Sherman and Grant Townships	Guardrail	$84,278.50	$38,049.36	7.44	2.21
8	2013 HRRR	Lapeer County Road Commission	Elba Road from Lippincott Road to Coldwater Road in Elba/Oregon Townships; Clark Road from Newark Road to Turrill Road in Lapeer Township	Center Line Rumble Strips; Clearzone; Sign Upgrades; Guardrail	$416,798.44	$143,496.62	5.67	2.90
9	2013 HRRR	Kent County Road Commission	68th Street east of Morse Lake Avenue in Bowne Township	Vertical Alignment; Sight Distance Improvements	$247,161.47	$120,063.16	4.83	2.06
10	2013 STH	Cass County Road Commission	Dowagiac Creek Bridge at Middle Crossing Street, Dutch Settlement Street, and Indian Lake Road	Guardrail	$126,901.48	$36,442.86	4.73	3.48

The most cost-effective project as determined by the BCR was the sign upgrades that were performed in Oceana County. The sign upgrades installed along 72nd Avenue and at the intersections of York Road and Warren Road, 192nd Avenue and Wilke Road, and Oceana Drive and Monroe Road demonstrated a statistically significant reduction in FI crashes (92.8 percent) and PDO crashes (94.76 percent). Two other projects in Grand Traverse County and Lapeer County incorporated sign upgrades and also demonstrated top-ten benefits in terms of BCR. Traffic signal upgrades at two intersections in Lapeer county also demonstrated large benefits with a statistically significant 56.3 percent reduction in FI crashes.

6. Summary

This document represents a comprehensive post-installation study of the 2013 HSIPs, including safety funding distributed as a part of the STH and HRRR components. The existing site conditions, project costs, and details as well as historical traffic crash and volume data were collected for 39 total projects in order to assess the change in safety performance via traditional and HSM techniques. **Table 6-1** demonstrates the safety effectiveness as determined by both traditional and EB-method evaluations at the aggregate program-level as well as whether or not the result of the EB-method was statistically significant.

Table 6-1 - Post-Installation Analysis of 2013 HSIP Programs

Program	Traditional Crash Reduction			EB-Method Safety Effectiveness			Statistically Significant at 95%?		
	FI	PDO	Total	FI	PDO	Total	FI	PDO	Total
2013 STH	19.9%	-12.0%	-3.7%	50.5%	21.6%	29.9%	Yes	Yes	Yes
2013 HRRR	28.6%	44.8%	20.2%	28.7%	62.6%	61.2%	Yes	Yes	Yes

While the results of the traditional post-installation evaluation indicate potentially improved safety performance, further study via the EB-method suggests even greater improvements. Further consideration of project-level results should be given (and are provided in the Appendices) and provide further context as to the safety performance of each program.

Additional analyses were completed in order to assess the change in safety performance due to specific treatments, as described in Sections 4.1.2 and 4.2.2 related to the traditional and EB-method evaluations, respectively. Additionally, an economic analysis was also provided in order to determine the BCR and TOR for each project and program, which are summarized in **Table 6-2**.

Program	Implementation Cost	Annual Cost	Annual Benefit	B/C	TOR
2013 STH	$5,851,427.56	$586,661.80	$5,448,003.43	9.29	1.07
2013 HRRR	$2,455,366.90	$209,219.25	$1,242,406.23	5.94	1.98

Benefits are realized by both the 2013 STH and 2013 HRRR programs which is consistent with the safety analysis results. It is also important to consider the results of specific projects within each program when considering these results (Appendices).

Ultimately, the results of this study provide MDOT with a more data-driven approach to the selection criteria for future HSIPs. Future work in this area should include additional post-installation evaluation of these programs as well as research to improve data-driven approaches to traffic safety.

Appendices

Appendix A. Project Post-Installation Traditional and EB Evaluation Results

Project Information			Traditional Evaluation								
			Pre-Installation Annual Crashes			Post-Installation Annual Crashes			Crash Reduction		
Project Number	County	Job Number	FI	PDO	TOT	FI	PDO	TOT	FI	PDO	TOT
2013 HRRR-1	Alger	115509	0.2	0.4	0.6	0.6	0.8	1.4	-200%	-100%	-133%
2013 STH-9	Allegan	117372	0.2	0	0.2	0	0	0	100%	N/A	100%
2013 STH-10	Arenac	117377	0	0	0	0.4	0.8	1.2	N/A	N/A	N/A
2013 HRRR-2	Barry	115512	1.2	2.8	4	0.6	1.4	2	50%	50%	50%
2013 STH-11	Bay	117378	0.6	0.4	1	0.4	0	0.4	33%	100%	60%
2013 STH-12	Benzie	117379	0	0.2	0.2	0	0	0	N/A	100%	100%
2013 STH-38	Cass	113579	0	0	0	0	0	0	N/A	N/A	N/A
2013 STH-13	Cheboygan	117389	0	0	0	0	0	0	N/A	N/A	N/A
2013 STH-14	Clinton	117394	1	2.8	3.8	0.2	2.2	2.4	80%	21%	37%
2013 STH-17	Genessee	117402	0.6	1.4	2	0.4	0.8	1.2	33%	43%	40%
2013 STH-15	Genessee	117397	4.2	6	10.2	3.4	8.4	11.8	19%	-40%	-16%
2013 STH-16	Genessee	117401	0.8	1.6	2.4	0.8	1.4	2.2	0%	13%	8%
2013 STH-18	Grand Traverse	117403	11.2	56.8	68	13.2	63	76.2	-18%	-11%	-12%
2013 STH-19	Grand Traverse	117404	0.6	0.8	1.4	0.6	0	0.6	0%	100%	57%
2013 STH-20	Houghton	117413	0.2	0.6	0.8	0.4	0.6	1	-100%	0%	-25%
2013 STH-21	Ionia	117883	0.4	1.2	1.6	0.6	1.2	1.8	-50%	0%	-13%
2013 HRRR-3	Ionia	115519	1.4	1.4	2.8	0	0.8	0.8	100%	43%	71%
2013 STH-22	Iosco	117415	0	0.4	0.4	0.2	0.4	0.6	N/A	0%	-50%
2013 STH-23	Kent	117425	3	3.6	6.6	2.2	6.4	8.6	27%	-78%	-30%
2013 STH-24	Kent	117427	2.8	4.6	7.4	0.4	3.2	3.6	86%	30%	51%
2013 HRRR-4	Kent	115521	0	0.2	0.2	0.4	0	0.4	N/A	100%	-100%
2013 STH-25	Keweenaw	117438	0.2	0	0.2	0	0	0	100%	N/A	100%
2013 HRRR-5	Lapeer	115523	1.8	5	6.8	1.8	2.4	4.2	0%	52%	38%
2013 HRRR-6	Lapeer	115524	2	7.2	9.2	1.2	3.2	4.4	40%	56%	52%

Project Information			Traditional Evaluation								
			Pre-Installation Annual Crashes			Post-Installation Annual Crashes			Crash Reduction		
Project Number	**County**	**Job Number**	**FI**	**PDO**	**TOT**	**FI**	**PDO**	**TOT**	**FI**	**PDO**	**TOT**
2013 STH-26	Lapeer	117441	1.6	4.6	6.2	0.8	5.4	6.2	50%	-17%	0%
2013 STH-27	Livingston	117442	8.4	23	31.4	5.4	26.6	32	36%	-16%	-2%
2013 STH-37	Luce	113632	0	0	0	0	0	0	N/A	N/A	N/A
2013 STH-28	Mackinac	117441	0	0	0	0	0	0	N/A	N/A	N/A
2013 STH-29	Manistee	117442	0.6	0.2	0.8	0.6	0	0.6	0%	100%	25%
2013 STH-30	Manistee	117886	0.4	2	2.4	0	1	1	100%	50%	58%
2013 HRRR-7	Montcalm	115527	0	0	0	0	0.2	0.2	N/A	N/A	N/A
2013 STH-31	Oceana	117887	1.6	1	2.6	0.6	0.6	1.2	63%	40%	54%
2013 STH-39	Osceola	113651	0.2	0.4	0.6	0.2	2	2.2	0%	-400%	-267%
2013 STH-32	Otsego	117458	0.4	0.4	0.8	0	0.2	0.2	100%	50%	75%
2013 STH-33	Otsego (City of Gaylord)	117459	0	0	0	0	0	0	N/A	N/A	N/A
2013 STH-34	Roscommon	117461	0.4	0	0.4	0.4	0.4	0.8	0%	N/A	-100%
2013 STH-35	Shiawassee	117467	0	0	0	0	0	0	N/A	N/A	N/A
2013 HRRR-8	St. Joseph	115531	0.4	0.4	0.8	0.4	0.8	1.2	0%	-100%	-50%
2013 STH-36	Washtenaw	117476	0.8	1	1.8	1	2	3	-25%	-100%	-67%

Project Information			EB Evaluation								
			Exp. w/o Treatment			Safety Effectiveness			Sig. at 95%		
Project Number	County	Job Number	FI	PDO	TOT	FI	PDO	TOT	FI	PDO	TOT
2013 HRRR-1	Alger	115509	0.31	0.55	0.87	-95%	-46%	-60%	No	No	No
2013 STH-9	Allegan	117372	0.28	0.38	0.66	100%	100%	100%	N/A	N/A	N/A
2013 STH-10	Arenac	117377	0.29	0.58	0.87	-39%	-38%	-39%	No	No	No
2013 HRRR-2	Barry	115512	1.78	3.57	5.34	66%	61%	63%	No	No	Yes
2013 STH-11	Bay	117378	0.73	0.64	1.39	45%	100%	71%	No	N/A	Yes
2013 STH-12	Benzie	117379	0.45	1.00	1.46	100%	100%	100%	N/A	N/A	N/A
2013 STH-38	Cass	113579	0.29	1.73	2.02	100%	100%	100%	N/A	N/A	N/A
2013 STH-13	Cheboygan	117389	0.17	0.75	0.93	100%	100%	100%	N/A	N/A	N/A
2013 STH-14	Clinton	117394	0.55	1.67	2.27	64%	-32%	-6%	No	No	No
2013 STH-17	Genessee	117402	0.50	1.90	2.40	20%	58%	50%	No	No	No
2013 STH-15	Genessee	117397	4.10	5.68	9.73	17%	-48%	-21%	No	No	No
2013 STH-16	Genessee	117401	0.83	2.12	2.96	4%	34%	26%	No	No	No
2013 STH-18	Grand Traverse	117403	13.81	49.62	63.43	4%	-27%	-20%	No	No	No
2013 STH-19	Grand Traverse	117404	2.60	4.75	7.33	77%	100%	92%	Yes	N/A	Yes
2013 STH-20	Houghton	117413	0.07	0.55	0.62	-477%	-9%	-61%	No	No	No
2013 STH-21	Ionia	117883	0.57	1.39	1.95	-6%	13%	8%	No	No	No
2013 HRRR-3	Ionia	115519	1.80	1.80	3.61	100%	56%	78%	N/A	No	Yes
2013 STH-22	Iosco	117415	0.33	2.91	3.24	40%	86%	81%	No	Yes	Yes
2013 STH-23	Kent	117425	4.27	6.57	10.85	48%	3%	21%	No	No	No
2013 STH-24	Kent	117427	3.22	6.88	10.10	88%	53%	64%	Yes	Yes	Yes
2013 HRRR-4	Kent	115521	1.84	3.39	5.22	78%	100%	92%	Yes	N/A	Yes
2013 STH-25	Keweenaw	117438	0.32	1.70	2.03	100%	100%	100%	N/A	N/A	N/A
2013 HRRR-5	Lapeer	115523	2.68	6.35	8.92	33%	62%	53%	No	Yes	Yes
2013 HRRR-6	Lapeer	115524	2.70	8.29	10.95	56%	61%	60%	No	Yes	Yes
2013 STH-26	Lapeer	117441	2.66	6.69	9.36	70%	19%	34%	Yes	No	No
2013 STH-27	Livingston	117442	12.35	35.49	47.93	56%	25%	33%	Yes	No	Yes
2013 STH-37	Luce	113632	0.05	0.13	0.18	100%	100%	100%	N/A	N/A	N/A
2013 STH-28	Mackinac	117441	0.00	0.01	0.02	100%	100%	100%	N/A	N/A	N/A
2013 STH-29	Manistee	117442	0.75	0.43	1.18	20%	100%	49%	No	N/A	No
2013 STH-30	Manistee	117886	0.61	2.31	2.93	100%	57%	66%	N/A	No	Yes

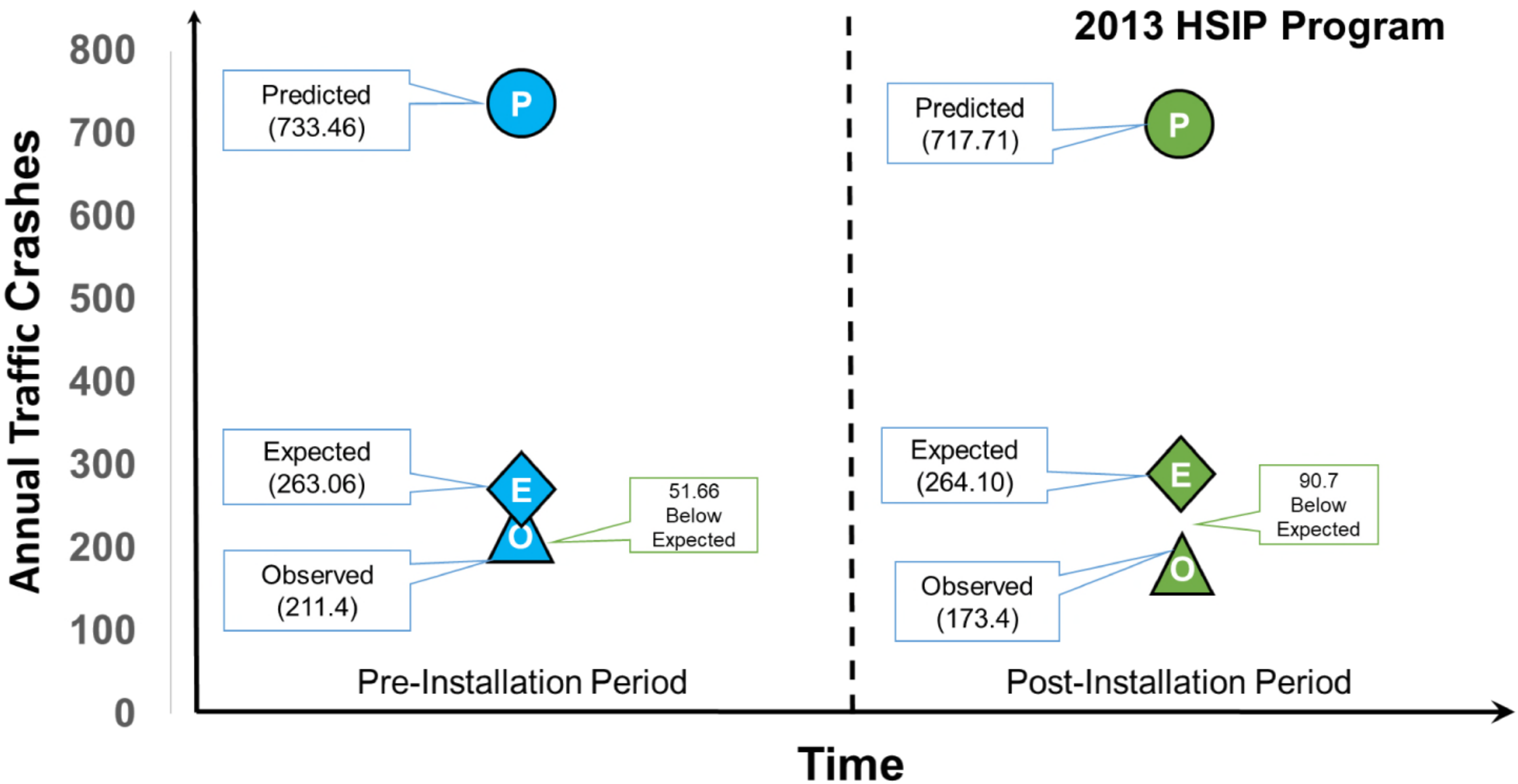
Project Information			EB Evaluation								
			Exp. w/o Treatment			Safety Effectiveness			Sig. at 95%		
Project Number	**County**	**Job Number**	**FI**	**PDO**	**TOT**	**FI**	**PDO**	**TOT**	**FI**	**PDO**	**TOT**
2013 HRRR-7	Montcalm	115527	0.33	0.96	1.29	100%	79%	84%	N/A	Yes	Yes
2013 STH-31	Oceana	117887	8.42	11.45	19.73	93%	95%	94%	Yes	Yes	Yes
2013 STH-39	Osceola	113651	2.94	5.43	8.36	93%	63%	74%	Yes	Yes	Yes
2013 STH-32	Otsego	117458	0.62	0.65	1.27	100%	69%	84%	N/A	No	Yes
2013 STH-33	Otsego (City of Gaylord)	117459	0.39	1.35	1.73	100%	100%	100%	N/A	N/A	N/A
2013 STH-34	Roscommon	117461	0.61	2.41	3.02	35%	83%	73%	No	Yes	Yes
2013 STH-35	Shiawassee	117467	0.19	1.13	1.32	100%	100%	100%	N/A	N/A	N/A
2013 HRRR-8	St. Joseph	115531	0.65	0.76	1.42	39%	-5%	15%	No	No	No
2013 STH-36	Washtenaw	117476	2.03	3.13	5.24	51%	36%	43%	No	No	No

Appendix B. Project Post-Installation Economic Results

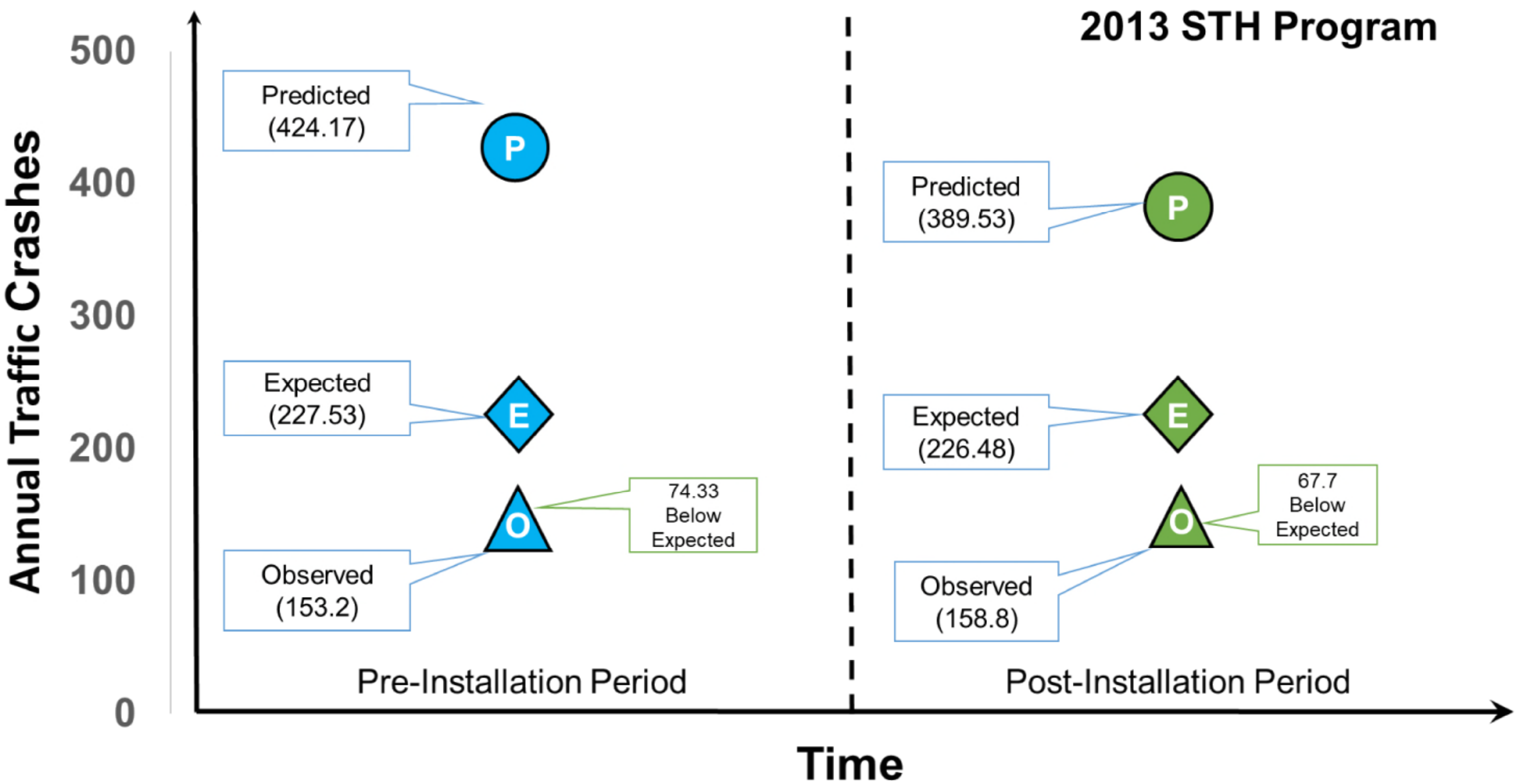
Project Information			Economic Analysis				
Project Number	County	Job Number	Annual Benefit	Implementation Cost	Annual Cost	B/C	TOR
2013 HRRR-1	Alger	115509	$ (19,153.12)	$ 450,064.25	$ 43,591.03	-0.44	-23.50
2013 STH-9	Allegan	117372	$ 20,168.51	$ 340,229.63	$ 34,054.63	0.59	16.87
2013 STH-10	Arenac	117377	$ (8,812.90)	$ 202,904.42	$ 13,439.57	-0.66	-23.02
2013 HRRR-2	Barry	115512	$ 91,082.18	$ 160,131.75	$ 9,715.84	9.37	1.76
2013 STH-11	Bay	117378	$ 25,576.89	$ 537,165.86	$ 67,975.18	0.38	21.00
2013 STH-12	Benzie	117379	$ 36,491.95	$ 180,611.48	$ 13,215.51	2.76	4.95
2013 STH-38	Cass	113579	$ 36,442.86	$ 126,901.48	$ 7,699.62	4.73	3.48
2013 STH-13	Cheboygan	117389	$ 18,530.24	$ 126,010.18	$ 8,774.09	2.11	6.80
2013 STH-14	Clinton	117394	$ 13,127.12	$ 56,048.48	$ 6,739.35	1.95	4.27
2013 STH-17	Genesee	117402	$ 18,518.01	$ 52,073.00	$ 4,288.02	4.32	2.81
2013 STH-15	Genesee	117397	$ 6,515.61	$ 75,338.00	$ 14,213.60	0.46	11.56
2013 STH-16	Genesee	117401	$ 10,206.76	$ 27,357.48	$ 6,059.17	1.68	2.68
2013 STH-18	Grand Traverse	117403	$ (125,562.98)	$ 19,000.00	$ 9,449.68	-13.29	-0.15
2013 STH-19	Grand Traverse	117404	$ 167,205.34	$ 13,000.00	$ 1,128.73	148.14	0.08
2013 STH-20	Houghton	117413	$ (18,835.88)	$ 81,431.34	$ 13,177.04	-1.43	-4.32
2013 STH-21	Ionia	117883	$ 439.37	$ 279,254.54	$ 25,374.84	0.02	635.58
2013 HRRR-3	Ionia	115519	$ 111,610.25	$ 548,268.24	$ 48,731.97	2.29	4.91
2013 STH-22	Iosco	117415	$ 37,130.09	$ 166,598.60	$ 10,108.21	3.67	4.49
2013 STH-23	Kent	117425	$ 116,048.96	$ 574,326.31	$ 55,851.55	2.08	4.95
2013 STH-24	Kent	117427	$ 199,232.46	$ 84,776.82	$ 9,960.75	20.00	0.43
2013 HRRR-4	Kent	115521	$ 120,063.16	$ 247,161.47	$ 24,845.44	4.83	2.06
2013 STH-25	Keweenaw	117438	$ 38,049.36	$ 84,278.50	$ 5,113.52	7.44	2.21
2013 HRRR-5	Lapeer	115523	$ 95,667.11	$ 351,728.50	$ 21,340.79	4.48	3.68
2013 HRRR-6	Lapeer	115524	$ 143,496.62	$ 416,798.44	$ 25,288.84	5.67	2.90
2013 STH-26	Lapeer	117441	$ 118,266.86	$ 516,400.32	$ 47,436.49	2.49	4.37
2013 STH-27	Livingston	117442	$ 489,546.31	$ 155,133.91	$ 2,526.92	193.73	0.32
2013 STH-37	Luce	113632	$ 4,357.02	$ 31,350.75	$ 2,722.03	1.60	7.20
2013 STH-28	Mackinac	117441	$ 401.16	$ 93,787.11	$ 8,143.07	0.05	233.79
2013 STH-29	Manistee	117442	$ 13,467.91	$ 83,150.40	$ 5,045.07	2.67	6.17
2013 STH-30	Manistee	117886	$ 49,499.13	$ 93,177.50	$ 11,475.77	4.31	1.88

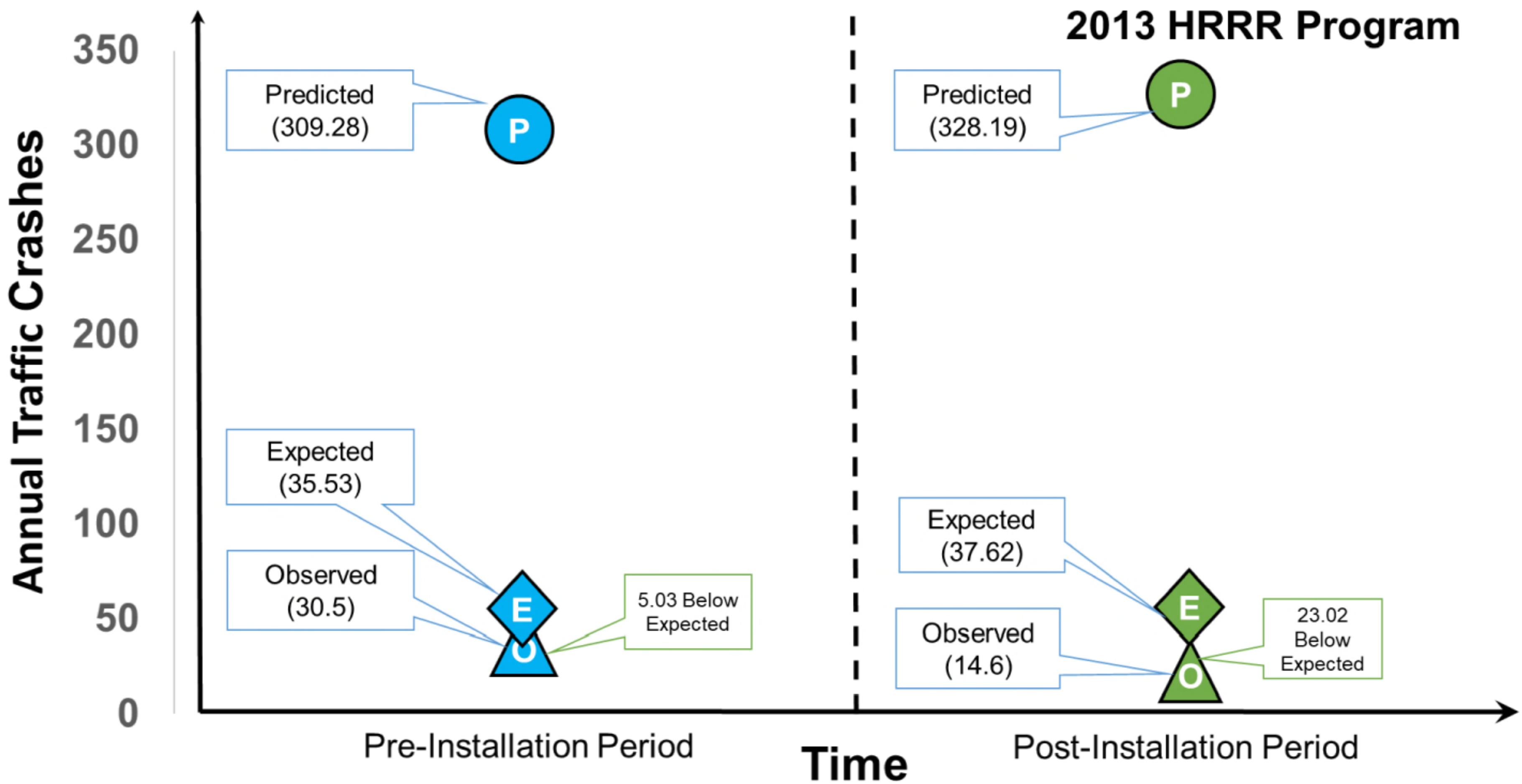
Project Information			Economic Analysis				
Project Number	County	Job Number	Annual Benefit	Implementation Cost	Annual Cost	B/C	TOR
2013 HRRR-7	Montcalm	115527	$ 27,269.56	$ 256,135.65	$ 34,183.73	0.80	9.39
2013 STH-31	Oceana	117887	$ 560,970.30	$ 15,450.98	$ 2,526.92	222.00	0.03
2013 STH-39	Osceola	113651	$ 192,357.03	$ 341,640.27	$ 44,464.92	4.33	1.78
2013 STH-32	Otsego	117458	$ 39,425.24	$ 489,576.78	$ 65,638.63	0.60	12.42
2013 STH-33	Otsego (City of Gaylord)	117459	$ 37,854.37	$ 188,679.72	$11,447.96	3.31	4.98
2013 STH-34	Roscommon	117461	$ 35,656.20	$ 204,584.50	$ 41,527.65	0.86	5.74
2013 STH-35	Shiawassee	117467	$ 23,746.00	$ 95,563.06	$ 5,798.20	4.10	4.02
2013 HRRR-8	St. Joseph	115531	$ 13,458.71	$ 25,078.60	$ 1,521.62	8.84	1.86
2013 STH-36	Washtenaw	117476	$ 70,225.67	$ 515,626.14	$ 31,285.12	2.24	7.34

Appendix C. EB-Method Program Result Figures



2013 HSIP Program
Annual Traffic Crashes
800
700
600
500
400
300
200
100
0
Predicted (733.46)
P
Expected (263.06)
E
O
51.66 Below Expected
Observed (211.4)
Pre-Installation Period
Predicted (717.71)
P
Expected (264.10)
E
90.7 Below Expected
O
Observed (173.4)
Post-Installation Period
Time


2013 STH Program
Annual Traffic Crashes
500
400
300
200
100
0
Predicted
(424.17)
P
Expected
(227.53)
E
O
74.33
Below
Expected
Observed
(153.2)
Pre-Installation Period
Predicted
(389.53)
P
Expected
(226.48)
E
O
67.7
Below
Expected
Observed
(158.8)
Post-Installation Period
Time


2013 HRRR Program
Annual Traffic Crashes
350
300
250
200
150
100
50
0
Predicted (309.28)
P
Expected (35.53)
E
Observed (30.5)
O
5.03 Below Expected
Predicted (328.19)
P
Expected (37.62)
E
Observed (14.6)
O
23.02 Below Expected
Pre-Installation Period
Time
Post-Installation Period

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